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(54) **Opto hydraulic servo valve**

(57) To operate a hydraulic valve in a dangerous environment, optical signals are conveyed to the valve via optical fibres (3, 4). At the receiving end, the optical signals are aimed at solar cells (1, 2), one of which responds to energize the valve's operating coil (2). Separate fibre-solar cell combinations are provided for opening and closing the valve.

In an alternative where there is no magnet, the valve's control member is a flapper with a light-absorbent layer on each face. Each fibre, one for on and one for off, is aimed at one of the layers, so that the direction of movement of the flapper depends on which fibre delivers a signal. Such a signal when absorbed by one of the layers heats it and causes the flapper to bend to exert the desired control. The flapper co-operates with control nozzles to operate the valve.

Fig.1.

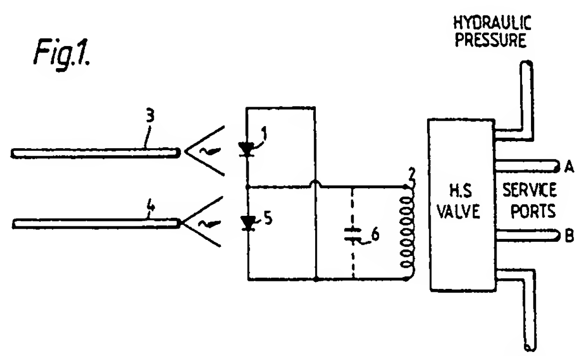
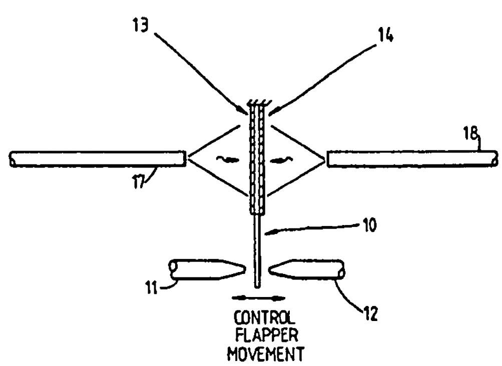


Fig.3.



The drawings originally filed were informal and the print here reproduced is taken from later filed formal copies.

Fig.1.

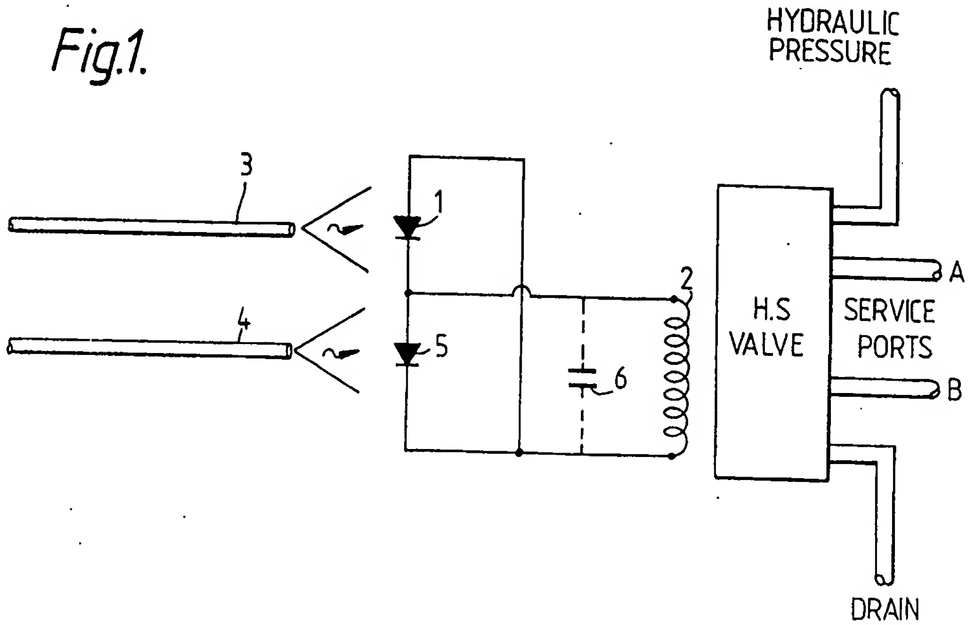

HYDRAULIC
PRESSURE
3
1
2
4
5
6
H.S
VALVE
SERVICE
PORTS
A
B
DRAIN

Fig.2.

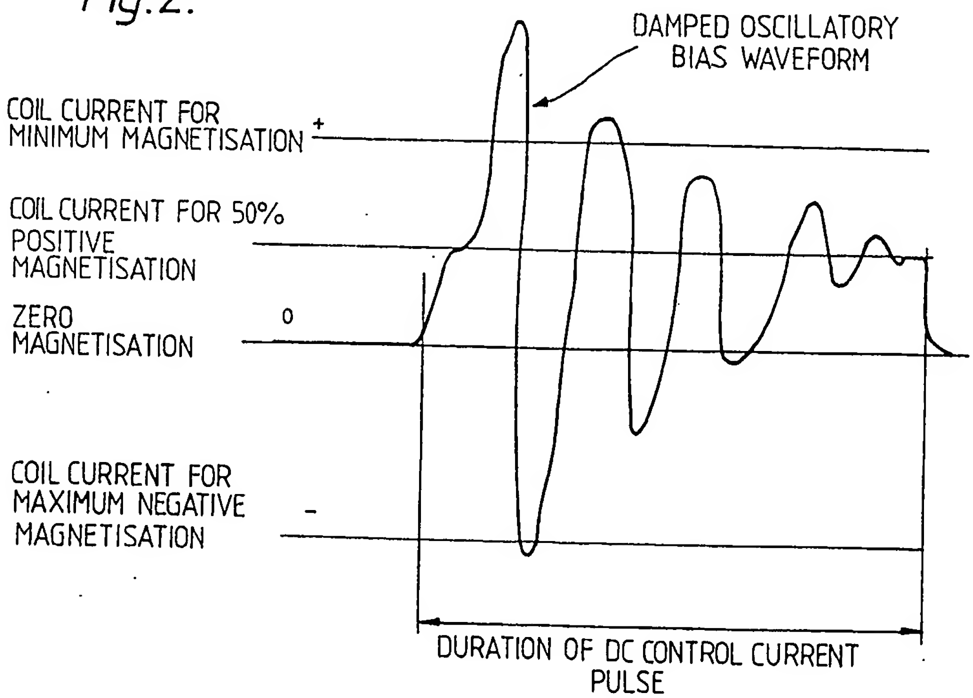
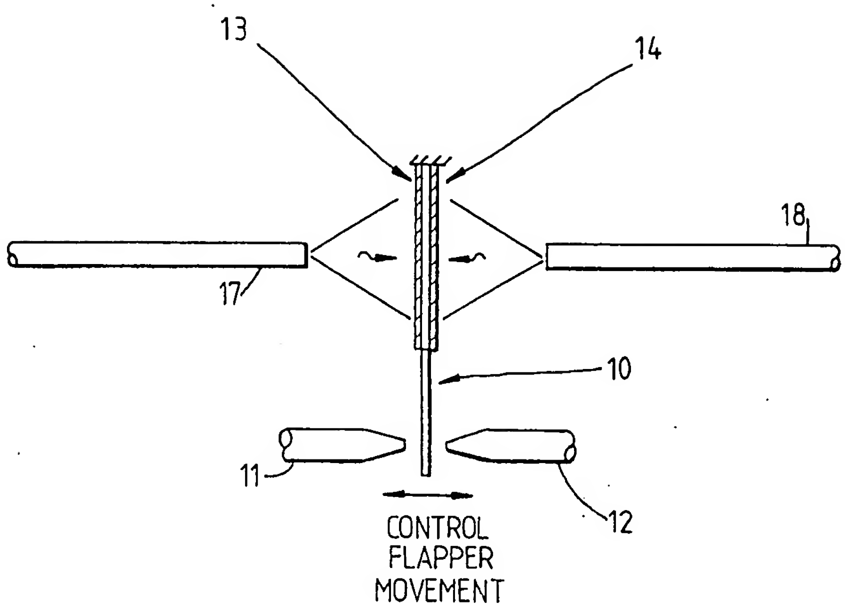

DAMPED OSCILLATORY
BIAS WAVEFORM
COIL CURRENT FOR
MINIMUM MAGNETISATION
+
COIL CURRENT FOR 50%
POSITIVE
MAGNETISATION
ZERO
MAGNETISATION
0
COIL CURRENT FOR
MAXIMUM NEGATIVE
MAGNETISATION
-
DURATION OF DC CONTROL CURRENT
PULSE

Fig.3.



SPECIFICATION

Opto-hydraulic servo valve

This invention relates to methods of and apparatus for the remote operation of a hydraulic servo valve especially when used in a hazardous environment.

One such valve is the Dowty 4551 series servo valve, which is a high performance two-stage device widely used in closed-loop position, velocity and face, control systems to provide fast precise control at high power levels. Such a valve has a pilot stage formed by a nozzle-flapper arrangement, the flapper being between two nozzles so as to control movement in either of two directions. The flapper is driven by a double air-gap dry torque moter. Applying a low power electrical signal to the valve results in pilot stage flow to the appropriate end of a four-way sliding spool, dependent on input signal polarity. This causes movement of the spool, whose position is fed back to the pilot stage by a simple cantilever spring. Thus the servo valve is a closed loop control system. The electrical input to the pilot stage effects proportional displacement of the spool, and hence proportional hydraulic flow to the load. The convenience of controlling a valve such as described above with low-power electrical signals can be offset by the fire and exposion risks introduced by electrical circuits in hazardous environments. An object of the invention is to enable a hydraulic valve to be remotely-controlled in a hazardous environment without the risks inherent in electrical connection thereto.

According to the invention there is provided a method of remotely operating a hydraulic servo-valve of the type having a control member settable to a first or a second condition to exert a controlling influence on the valve, which method includes transmitting a first optical signal via an optical fibre to the servo valve, directing the optical fibre at a light responsive device such that when a said signal falls thereon it exerts a controlling influence to set the control member towards a first condition thereof, transmitting a further optical signal via a further optical fibre to the valve, and directing the further optical fibre at a further light-responsive device such that when a said further signal falls on the further light-responsive device it exerts a controlling influence to set the control member towards a second condition thereof.

Thus the electrical hazard is eliminated by generating the remote control signals as light, and sending them to the valve through one or more optical fibres. The first method to be described below is applicable to a standard electro-hydraulic valve such as referred to above, but permits the electrical circuit to be confined safely within the valve casing. The second method totally eliminates the electrical transduction stage by arranging for the control flapper to be thermally displaced by light energy incident directly upon it from the optical fibres.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which Fig. 1 is a first embodiment of the invention using solar cells, Fig. 2 is a waveform diagram useful to explain an embodiment of the invention, and Fig. 3 is a fully non-electrical embodiment of the invention.

Solar Cell Transducer Method

In normal operation, the electro-hydraulic servo valve delivers fluid through one or other of its service ports, depending upon the polarity of the control current supplied to its magnet coil, the rate of flow being determined in an analogue relationship to the magnitude of this current. Zero control current results in no delivery from either port. In the present method, a solar cell 1, mounted within the valve housing, is connected directly across the magnet coil 2. The coil parameters and the solar cell area are such that, at a given maximum level of cell illumination, the current delivered to the coil by the solar cell is sufficient to open the valve fully. The requisite illumination is derived from light generated at the remote control centre and conveyed by an optical fibre 3 to be incident upon the solar cell 1. Variation of the intensity of the control light causes a corresponding variation in the hydraulic flow from the related service port. An alternative control method is to transmit a train of optical pulses of constant intensity but of variable width, the magnetic and mechanical integrating effects being sufficient to achieve the same result as the intensity-variable continuous control light. Since it is a feature of conventional electro-hydraulic valves that their performance may be enhanced by superimposing a 'dither' waveform upon the dc control signal, this effect is achieved by pulsing or otherwise varying the intensity of the fibre-conducted control light. Typically, for the Dowty valve referred to above, a dither frequency between 200 and 400 Hz is recommended, at an amplitude of less than $\pm 10\%$ of the control signal amplitude.

Since the optical mechanism so far described is inherently unidirectional in its control capability, reverse operation of the valve requires the provision of a second control fibre 4 and solar cell 5, so connected as to generate the requisite reverse current in the magnet coil 2. It is convenient that a silicon solar cell presents a high impedance, when unilluminated, to an applied voltage of opposite polarity to that which it self-generates when illuminated. This permits the simple arrangement of Fig. 1, in which the two cells are connected "back-to-back" directly across the magnet coil 2. Thus, when cell 1 is illuminated and cell 5

is in darkness, the output current is of such polarity as to initiate an outflow from service port A. Conversely, illuminating cell 5 initiates the flow from port B. Full control of the servo valve is thus achieved by transmitting the appropriate alternative optical signals through the two fibres.

Constant-intensity pulse control of the system might take the form of a square wave fed normally to cell 1 but inverted to cell 5, so that either all 1 or 5 is illuminated at any instant. A 50/50 mark/space ratio would then be integrated to give zero current in the magnet coil 1, the integration time-constant being increasable by the addition of, for example, a suitable value of capacitor 6 across the coil connections. Progressively increasing the pulse width fed to cell 1, at the expense of that fed to cell 5, gives rise to an increasing mean current of polarity such as progressively to increase the hydraulic flow from port A. Conversely, widening the optical pulses to cell 5, at the expense of cell 1, causes the progressive opening of port B. A convenient method for introducing the 'dither' feature would be to choose a pulse repetition frequency of, say, 300 Hz and integrate only sufficiently to leave a residual pulse component of about 10% amplitude superimposed upon the smoothed coil current.

Control Power Economiser

In the type of valve here discussed, the current in the control coil must be sustained continuously to maintain a given valve setting. To enable the control signal to be transmitted only briefly to set up the required condition, which signal falls to zero until such time as a new valve setting is required, the following modification is used. This is applicable to a normal, wire-connected valve, but is of particular advantage in the present optically-controlled system, where account must be taken of the relatively low transduction efficiency of the solar cells. The actuating magnetic armature in existing valve has to be of a 'soft' magnetic material, having low retentivity, so that it recovers to the null position between the associated permanent magnets when the coil current falls to zero. However, by making the armature of a high-retentivity material the control current drives the armature to the required level of permanent magnetism and polarity and is then switched off. The force applied to the armature then remains static at the requisite valve setting until a further control signal alters the state of magnetism of the armature. The method for achieving intermediate values of armature magnetisation is similar to that used in magnetic tape recording to overcome the non-linearity of the material's hysteresis loop. The control signal is at a direct current lead such as to raise the material to the required level and polarity of magnetisation, plus a superimposed AC component in the form of a damped oscillation, starting at a level sufficient to sweep the armature material through its complete hysteresis loop, whereafter it decays slowly to zero. The effect, as in the magnetic recording case, is to eliminate the backlash due to the finite coercivity of the material and to leave the material at the required level of magnetisation after the DC component is finally switched off, regardless of the previous magnetic history. Thus, the control signal might take the form of Fig. 2, a DC pulse of appropriate magnitude embracing the damped wave as described. One may think of the mechanism as one of demagntising the material towards the condition preset by the DC component. In the optical system described, this waveform may be generated by appropriate alterations in the intensity of the light transmitted down the two fibres.

Thermal Deflection Method

An alternative method for exploiting a control light transmitted down optical fibres is shown in Fig. 3. In this case, the control flapper 10 is constructed as a three-layer sandwich, rigidly attached at its upper end 10 and movable between two hydraulic control nozzles 11 and 12. The outer layers 13 and 14 are made of a material having a high coefficient of thermal expansion and the central layer is of a material with a high thermal resistivity. The output ends of the two control fibres 17 and 18 are presented, one to each side, so as to illuminate the surfaces of the two high-expansion layers 13 and 14. Control light issuing from one fibre raises the temperature of its associated layer, causing its length to increase. The insulating layer prevents the transfer of heat to the other outer layer, which retains its original dimensions. Hence, the flapper bends, after the manner of a bimetallic strip, to complete the control function. It will be evident that proportional control can be achieved by controlling the intensity of the incident light, and reverse operation by illuminating the other fibre. The efficiency of the system can be enhanced by coating the illuminated surfaces with a highly-absorptive black coating.

An alternative to the three-layer construction to use a single, homogeneous material combining high thermal expansion with high internal resistivity.

CLAIMS

1. A method of remotely operating a hydraulic servo-valve of the type having a control member settable to a first or a second condition to exert a controlling influence on the valve, which method includes transmitting a first optical signal via an optical fibre to the servo valve, directing the optical fibre at a light responsive device such that when a said signal falls thereon it exerts a controlling influence to set the control member towards a

first condition thereof, transmitting a further optical signal via a further optical fibre to the valve, and directing the further optical fibre at a further light-responsive device such that when a said further signal falls on the further light-responsive device it exerts a controlling influence to set the control member towards a second condition thereof.

2. Apparatus for the remote operation of a hydraulic servo-valve of the type having a control member settable to a first or a second condition to exert a controlling influence on the valve, which includes a first optical fibre via which a first control signal is received at a first light-responsive device associated with the valve, the fibre being directed at the device such that the signal is applied to that device, the response of the device to said signal causing the control member to be set towards its first condition, and a second optical fibre via which a second control signal is received at a second light responsive device also associated with the valve, the second fibre being directed at the second device such that the second signal is applied to that device, the response of the second device to the second signal causing the control member to be set towards its second condition.

3. Apparatus as claimed in claim 2, in which the light responsive devices are solar cells each of which is connected across an operating coil in the magnetic system of the valve, the two solar cells being so connected that they cause the coil to be energised in opposite magnetic sensors.

4. Apparatus as claimed in claim 3, and in which light signals each consist of a pulsed waveform.

5. Apparatus as claimed in claim 4, and in which the pulsed light signals are pulse width modulated.

6. Apparatus as claimed in claim 2, in which the valve is controlled by a flapper member located between two hydraulic control nozzles, in which the two light-responsive devices are layers of heat sensitive and highly expansive material on opposite faces of the flapper member, and in which when a light signal falls on one of said layers that layer absorbs heat from that light to cover the flapper to bend towards one of said nozzles to effect the required control.

7. Apparatus as claimed in claim 6, and in which the surfaces of said layers on which the light is incident are matt black.

8. A method of operating a hydraulic servo-valve, substantially as described with reference to Figs. 1, 2 or 3 of the accompanying drawings.

9. Apparatus for operating a hydraulic servo valve, substantially as described with reference to Fig. 1, 2 or 3 of the accompanying drawings.

CLAIMS

Amendments to the claims have been filed, and have the following effect:–

New claims have been filed as follows:–

10. Apparatus for remotely operating a hydraulic servo-valve of the type having a control member settable to a first or a second condition to exert a controlling influence on the valve, which apparatus includes:

(a) a first optical fibre via which a first optical signal may be transmitted to the servo-valve, which optical fibre is directed at a first light responsive device such as a solar cell, so that when a signal falls thereon it exerts a controlling influence which tends to set the control member to a first condition thereof;

(b) a further optical fibre via which a further optical signal may be transmitted to the valve, which further optical fibre is directed at a further light responsive device such as a solar cell, so that when a signal falls thereon it exerts a controlling influence which tends to set the control member to a second condition thereof;

(c) means for pulse modulating the light conveyed by the fibres such that in a rest condition the beam in each said fibre has a 50% mark to space ratio with the modulation on the two fibres in anti-phase, such that the control member is not moved in response to said modulated light; and

(d) means for varying the modulation mark to space ratios on the fibres when the control member is to be moved, which modulation is varied such as to increase the mark to space ratio in one fibre while reducing that ratio in the other fibre, whereby a gradual movement of the control member may be effected.

11. Apparatus as claimed in claim 10, in which the two light responsive devices are each connected across an operating coil in the magnetic system of the valve, the two devices being so connected that they cause the coil to be energised in opposite magnetic senses, and in which the movable means controlled by the coil are made of a magnetically hard material such that the controlled valve is maintained in its new setting without the need for continous setting current, the light signals only being sent for sufficient time to alter the setting of the movable means.

12. Apparatus for the control of a hydraulic servo-valve of the type having a control member settable to a first or a second condition to exert a controlling influence on the valve, wherein the valve is controlled by a flapper member located between two hydraulic control nozzles, wherein the apparatus includes a first optical fibre via which a first control signal may be received at a first light-responsive device associated with the valve, the fibre being directed at the device such that the signal is applied to that device, the response of the device to that signal tending to set the control member towards a first condition, wherein the apparatus also includes

a second optical fibre via which a second control signal may be received at a second light responsive device also associated with the valve, the second fibre being directed at the second device such that the second signal is applied to that device, the response of the second device to the second signal tending to set the control member towards a second condition, and wherein the two light responsive devices are layers of heat sensitive and highly expansive material on opposite faces of the flapper member, so that when a light signal falls on one of said layers that layer absorbs heat from that light to cause the flapper to bend towards one of the nozzles to effect the required control.

13. Apparatus as claimed in claim 12, and in which the portion of the flapper onto which the light signals are directed are integral with the central region of that portion, the whole thus being a single layer and being made of a material which combines high thermal expansion with high internal heat resistivity.

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